

Mars Exploration Architecture

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INTRODUCTION

The architecture of NASA's program of robotic Mars exploration missions received an intense scrutiny during the summer months of 1998. We present here the results of that scrutiny, and describe a list of Mars exploration missions which are now being proposed by the nation's space agency.

The heart of the new program architecture consists of missions which will return samples of Martian rocks and soil back to Earth for analysis. A primary scientific goal for these missions is to understand Mars as a possible abode of past or present life. The current level of sophistication for detecting markers of biological processes and fossil or extant life forms is much higher in Earth-based laboratories than possible with remotely deployed instrumentation, and will remain so for at least the next decade. Hence, bringing Martian samples back to Earth is considered the best way to search for the desired evidence.

A Mars sample return mission takes approximately three years to complete, as seen in Figure 1. Transit from Earth to Mars requires almost a single year. After a lapse of time of almost a year at Mars, during which orbital and surface operations can take place, and the correct return launch energy constraints are met, a Mars-to-Earth return flight can be initiated. This return leg also takes approximately one year.

Opportunities to launch these 3-year sample return missions occur about every 2 years, as shown in Figure 2. The figure depicts schedules for flights to and from Mars for Earth launches in 2003, 2005, 2007 and 2009. Transits for less than 180° flight angle, measured from the sun, and more than 180° are both shown.

BACKGROUND MISSIONS

The current and near-term planned missions, which precede sample return missions, are briefly described next. They are summarized in Figure 3.

In the 1996 launch opportunity, NASA launched two missions to Mars and thus began its first return to the red planet in over two decades. One of these missions was Mars Pathfinder, part of NASA's Discovery Program. It consisted

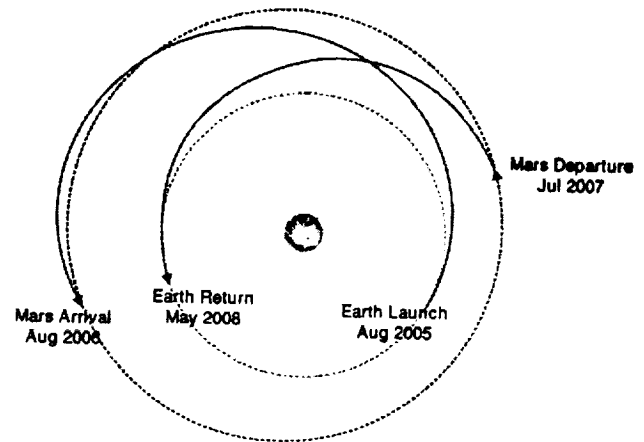


Figure 1 A Sample Return Mission takes approximately three years to complete. Example shown is the 2005 opportunity.

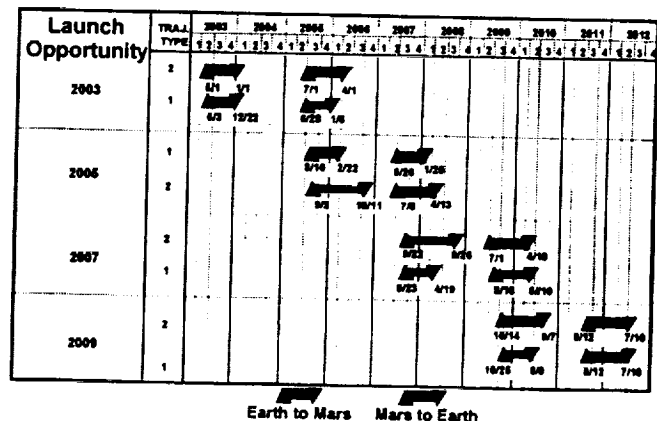


Figure 2 Key Mars opportunities for launch/return.

of a lander and a rover named Sojourner that was about the size of a microwave appliance. They landed on July 4, 1997, and gathered significant scientific data on the soil, rocks, and other elements of their environment and demonstrated important new technologies. In addition, they generated unprecedented public interest, as demonstrated by the record-breaking activity on the World Wide Web.

The other mission launched in 1996 is an orbiter called Mars Global Surveyor (MGS), the first in a series of missions

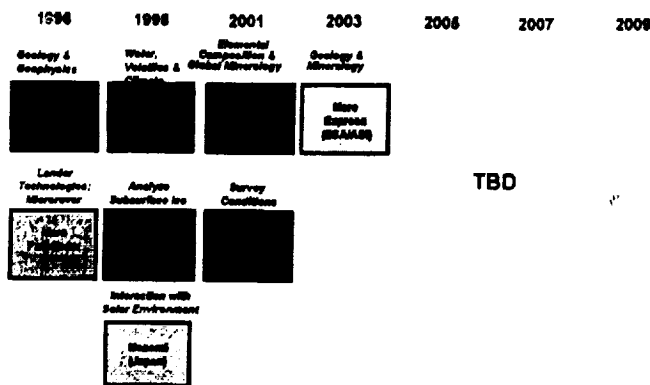


Figure 3 Mars Exploration background missions.

comprising NASA's Mars Surveyor Program. The Mars Surveyor Program was formally established in 1994 to embark on a continuous exploration of Mars with the long-range goal of understanding Mars in terms of Life, Climate, and Resources (see Figure 4). The missions are to look for evidence of past or present life; to understand the weather, climate processes, and climate history; and to identify the main environmental resources and their potential uses. A unifying theme is water, understanding where on Mars it may be now and the role it played in Martian history. The budget for the Program was initiated at about \$160M per year, including launch vehicles and mission operations. Beginning with fiscal year '98, the Program's budget was augmented by \$40 to \$60M per year, along with an increased focus on the life issues previously described. The Mars Surveyor Program is the core of the currently-funded exploration of Mars.

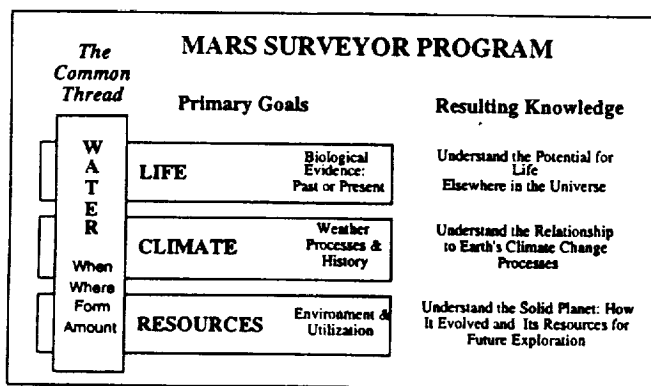


Figure 4 The primary goals of the Mars Surveyor Program.

MGS reached Mars in September 1997 and has since been using a technique called aerobraking to reach its proper mapping orbit. This technique requires that the orbiter skim the atmosphere of Mars to reduce speed and, thus, the size of the orbit. The use of the Martian atmosphere to adjust the orbit of the spacecraft greatly reduced the propellant requirement, thus enabling the use of a lower-cost launch vehicle than otherwise would have been needed. Even though the prime science mission isn't scheduled to begin until March 1999, much science data have already been collected, with key results having to do with the planet's

magnetic field, its mineralogy and topography, the topology of the northern polar cap, and thick dust on the moon Phobos.

Two spacecraft currently en route to Mars will be joining MGS toward the end of 1999. Mars Climate Orbiter, launched in December 1998, and Mars Polar Lander, launched in January 1999, will focus on the climate of Mars and search for clues to the reasons for its dramatic changes over time. Key objectives are to understand how water and dust move about the planet and to find clues to the location of water on Mars today. The orbiter carries instruments to map the planet's surface, profile the structure of the atmosphere, and possibly detect surface ice reservoirs. The lander will search for evidence of water beneath the surface at its landing site near the south pole of Mars. With a robotic arm and attached camera it will dig a trench several centimeters deep and examine in detail the fine-scale layering, if any, along the walls of the trench. It will also deliver a small sample of soil to a miniature oven. An instrument will analyze the volatiles that are generated when the sample is heated and measure their concentrations. Water vapor would demonstrate that water in some form was embedded in the soil.

Mars Polar Lander is also carrying to Mars two basketball-sized probes called Deep Space 2. These probes are part of NASA's New Millennium Program, the purpose of which is to test out new technologies. The microprobes will separate from the lander just before reaching Mars and will smash into the surface with an acceleration of about 80,000g. Each probe is designed to break into two parts at this time. The aftbody will remain on the surface and relay data from the probe to MGS for transmission back to Earth. The forebody will bury itself below the surface up to about a meter in depth. As does Mars Polar Lander, these penetrators also carry instruments to search, in two additional sites, for evidence of water.

The Mars Surveyor Program will continue with the launch of an additional pair of spacecraft in 2001. A lander will carry a small rover called Marie Curie, a slightly-modified flight spare of Sojourner. It will analyze the rocks and soil in a near-equatorial region to be chosen before launch, with the selected site to be targeted in flight. The lander will also carry three instruments in support of the possible future human exploration of Mars: a dust and soil characterization experiment, a demonstration of producing rocket fuel from the Martian atmosphere, and a radiation monitor. The second spacecraft is an orbiter which, from a near-polar orbit, will use remote sensing instruments to map the temperatures and elemental composition of the surface, and to search for near-surface reservoirs of water. This spacecraft will also monitor radiation, but from orbit, and these measurements will be used together with those from the surface to enhance significantly our understanding of the radiation environment at Mars.

The European Space Agency (ESA) and the Italian space agency (ASI) together are planning an orbiter to be launched to Mars in June 2003. The mission, called Mars Express, will be the first of a new class of "flexible" missions in the

revised ESA long-term scientific program. The payload will consist of a significant set of remote-sensing instruments, nearly all with significant heritage from European instruments lost with the Russian Mars 96 mission. Examples are: a stereo imager that will provide global 10-meter-resolution photogeology of the Martian surface and an infrared mapping spectrometer to obtain global mineralogy maps with 100-meter-resolution. A new instrument, to be provided by an ASI/NASA partnership, is a radar sounder that will map the subsurface structure of Mars at the kilometer scale down to the permafrost. Mars Express is also planning to carry a small surface lander, called Beagle 2, provided by a UK consortium led by the Planetary Sciences Research Institute, which will land as Pathfinder did using airbags. It will carry a 60-kg package of exobiology, geochemistry, and atmospheric chemistry investigations.

A Japanese mission called Nozomi, launched on July 4, 1998, exactly one year after the Pathfinder landing, will be arriving at Mars in December 2003. From a highly elliptical orbit, Nozomi will study the structure and dynamics of the upper atmosphere of Mars and its interaction with the solar wind.

Arriving in 2006 will be NetLander, a network of four small spatially-dispersed surface stations which will make simultaneous measurements on magnetism, seismology, and meteorology. To be built in Europe, these landers, each within its own aeroshell, will be carried to Mars by the CNES orbiter being planned for launch in 2005 (see below).

SAMPLE RETURN MISSIONS

As depicted in Figure 5, the sample return mission architecture begins in 2003 with the launch of a large Martian surface lander on a Delta III or Atlas IIIA class launch vehicle. The lander will carry a large, 100 kg, surface rover which will be deployed to cover a wide area, perhaps a square kilometer or more, to search for suitable rocks to sample. The rover will use a variety of instruments to select the most promising rocks which might contain biological evidence. Rover instrumentation will drill into several selected rocks, obtain small sample cores from each, and return the sets to the lander. The rover may perform multiple excursions to collect rock and soil samples. The rover will deposit these samples in the payload canister of a solid rocket propelled ascent vehicle. The lander may carry a coring drill which will allow subsurface samples to augment those collected by the rover for a total sample mass of under half a kilogram. The ascent rocket will be fired to lift the payload sample canister into a circular orbit, 600 km above the Martian surface, where it will await pickup by an orbiter.

In 2005 NASA is planning to send a second lander-rover combination to Mars on a French Ariane 5 launch vehicle. The 2005 lander and rover will be duplicates of the 2003

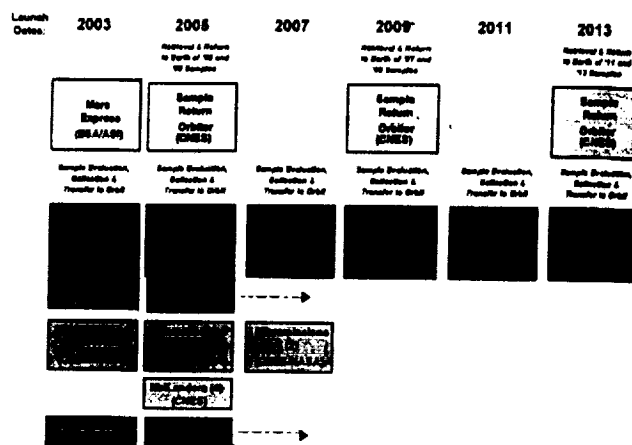


Figure 5 Missions in the Mars Exploration Architecture.

vehicles, and perform essentially the same functions: depositing into orbit a second sample-filled canister into a nearly identical Martian orbit.

The same Ariane 5 launch vehicle which carries the U.S. lander will also carry a Mars orbiting spacecraft supplied by the French National Space Agency (CNES). This Mars orbiter will pick up both the canisters and bring them back to Earth. The orbiter is first maneuvered into the same orbit as the canisters and then will autonomously rendezvous and dock with each canister, in turn, using both radio and optical canister sighting techniques. Once collected by the spacecraft, the canisters will be imbedded in Earth return atmospheric re-entry capsules. The capsules are carried back to Earth by the orbiter and released into the Earth's atmosphere in 2008, after which they will then land at a suitable retrieval site. Figure 6 depicts a schematic of the 2003 and 2005 missions.

By implementing this baseline plan, the missions described above will bring two distinct sample sets back to Earth in 2008 from two distinct locations on Mars. These highly protected samples will then be analyzed in Earth laboratories with a focus on the search for markers of biological processes or evidence of fossil or existing life forms.

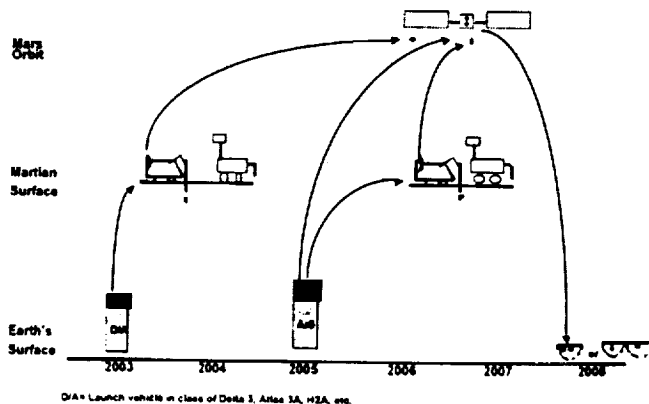


Figure 6 Schematic of Mars 2003/2005 Sample Return Missions.

MICROMISSIONS

The sample return missions as described above are expected to comprise the backbone of the NASA Mars exploration program for the next 10-15 years. In addition to these major mission undertakings, NASA also plans a line of smaller complementary missions, called micromissions. These micromissions will gather knowledge only, not samples for return, and will continue the NASA solar system exploration tradition of global planetary surveying and selected, high-resolution site reconnaissance.

The micromission line will begin with launches in 2003 or 2005, depending on the available budget wedge. A generic spacecraft bus will be developed, which can be replicated to carry science payloads to Mars for several opportunities. These micromissions may be launched on small U.S. supplied launches like the Taurus or as auxiliary payloads on commercial flights of the French Ariane vehicle. Science payload mass will approach 20 kg on the surface of Mars or 10 kg in orbit about Mars. Micromission payloads may include surface penetrators, aerial platforms like atmospheric balloons and gliders, small landers, and remote-sensing orbiters.

INTERNATIONAL CONTRIBUTIONS

NASA thus envisions a balance of missions in the Mars program architecture, with major sample return endeavors both within the U. S. and in partnership with CNES, and complimentary science data gathering micromissions whose carrier bus is developed by American industry. Below we describe some of the expected contributions from the international partners.

Space agencies around the world have a strong interest in Mars exploration. This interest, along with NASA's plans for a challenging program capped by a modest budget, creates a natural potential for international partnerships. Pursuing such relationships has been a guideline for the Mars Surveyor Program from its beginning. Discussions have been underway with several space agencies for several years to explore and develop opportunities for cooperation. Although formal agreements have not yet been completed, current assumptions in the Architecture are described here. Additional cooperative endeavors are also possible.

To establish the framework for the discussion, the key elements envisioned for NASA's contribution are described first.

NASA will provide the landers, sample gathering rovers, and Mars ascent vehicles beginning with the 2003 launch. They may also provide some additional lander-based science payload starting with the 2005 launch. On the orbiters, to be provided by the French (see below), NASA will supply the equipment needed to find and track the sample canisters. This is expected to consist of a camera as well as a receiver to track the beacons mounted on the orbiting canisters. In

addition, on each orbiter NASA will provide the sample capturing device, yet to be defined, as well as the Earth entry capsule into which the samples will be inserted and eventually ride safely through Earth's atmosphere to the landing site.

NASA has several contributions to Mars Express (see earlier discussion). Through the Mars Surveyor Program it has a partnership on the Italian-led radar sounder and supports numerous co-investigators on other experiments. Through the Discovery Program, it provides an instrument to analyze space plasmas and energetic atoms.

Other NASA contributions include launch vehicles in the class of Delta III/Atlas IIIA or Delta IV/Atlas V, beginning in 2003 and continuing as needed and the design and production of the micromission bus, as well as some associated payloads.

The French Space Agency, CNES, will fill a key role in the baseline Architecture for the Mars Surveyor Program. According to this plan, one essential item that CNES will provide is an Ariane 5 launch vehicle for the 2005 opportunity (only). Launching from French Guyana, this European rocket will have the capability to inject 5200 kg to Mars at the required launch energy of $18 \text{ km}^2/\text{s}^2$. This is sufficient to carry both the orbiter and lander which, after separating from the launch structure, will cruise independently to Mars.

A second major contribution by CNES is the sample return orbiter which will be launched starting in 2005. After entering Mars orbit, employing an aerocapture technique for the first time, the 2005 orbiter will have enough propellant to match orbits with both the 2003 and 2005 sample canisters in turn. Although the initial stages of each rendezvous will be directed through ground interaction using data from the U.S.-supplied tracking equipment carried on the orbiter, the final phase, including capture of the canister, will necessarily be autonomous. The orbiter will inject out of Mars orbit and bring the Earth entry capsule back to Earth and accurately target it for landing at the designated landing site. After releasing the capsule, the orbiter will perform a deflection maneuver and fly past the Earth. In addition to the sample return function, the orbiter will deliver NetLander to Mars. The four probes will be released prior to Mars orbit insertion.

CNES will also provide the launch opportunities for micromissions on commercial Ariane vehicles, perhaps as early as 2003 and contribute to some payloads.

ASI, the Italian space agency, may provide a drill for the landers in 2003 and beyond to enable subsurface samples to be collected and included in the sample canister along with the rover-based sample set. This complementary sample type, perhaps with an additional Italian science package, would add important diversity of science data and robustness to the missions.

ASI has a major role in the Mars Express orbiter in that they provide the telecom system. This system provides

two-way communication between the spacecraft and Earth and also provides the telecom relay function for the Beagle 2 Lander. It may also be used to provide this same relay function for the NetLanders. Because of the existence of this telecom capability in the 2004 to 2007 time frame, it could be applied to enhance the communication between Mars Surveyor landed elements and Earth. It could also help with the task of locating and positioning the first sample canister in Mars orbit in 2004, providing valuable *a priori* data for operating the Mars Surveyor 2005 orbiter. In addition to telecom, the operations team for Mars Express will be joint between ESA and ASI; this budget sharing will enable the operational lifetime to be extended into mid-2007. In addition, one of the Earth-based stations that will be used by Mars Express is the Italian antenna being developed on Sardinia. Among the ASI roles in the Mars Express payload, the Principal Investigator for the sub-surface radar sounder is Italian, as previously mentioned.

ESA will be responsible for the Mars Express mission. They will provide the launcher, orbiter, and operations team, the last jointly with ASI. The orbiter will carry a robust payload and gather important science data, as described early in this paper, data which will complement and enhance the Mars Surveyor Program in many areas. In particular, this orbiter is the vehicle for delivering and operating the ASI/NASA subsurface radar sounder at Mars. In addition, if Mars Express can provide to the Mars Surveyor operations team *a priori* data on the position of the 2003 sample canister in Mars orbit, the 2005 sample return orbiter can be targeted for an orbit insertion that makes the rendezvous with the sample canisters more efficient, both in terms of schedule and propellant.

LONG TERM PROGRAM

Several options exist for a continuation of the program architecture beyond the 2003 and 2005 sample return missions, but the basic character of the architecture is expected to extend throughout, at least, the first decade of the new millennium. If desired, the sample return missions launched in 2003 and 2005 can be repeated in 2007 and 2009 again in 2011 and 2013 and could produce a return of six sample sets back to Earth from six distinct Martian sites by 2016. In addition, the possible infusion of new technologies into those more distant missions may lead to increases in the amount and diversity of the returned sample sets as well as increases in the area of collection coverage.

The pace of sample returns can be slowed down in future years, with the reclaimed budget deployed to increase the number of micromission per launch opportunity or to refocus the direction of the program.

TELECOMMUNICATIONS

Primary communications to the 2003 and 2005 launched landers on Mars will be achieved through an x-band radio link between the landers and the NASA Deep Space Net. In addition, the 2003 and 2005 landers will be

communications-compatible with other orbiting assets like the NASA 2001 Surveyor orbiter and the ESA Mars Express orbiter. Also, the NASA Office of Space Flight is making plans to send dedicated communications orbiters to Mars as early as 2003. If their plans are carried out, the micromission concept, described earlier, would be applied to a 2003-launched equatorial telecom orbiter, which would service the landed elements for at least five years. Current plans call for a follow-on aerostationary orbiter to be launched in 2005 and additional low-orbit craft, both equatorial and polar, in the following years. The Office of Space Flight, therefore, will be supplying a permanent telecommunication infrastructure at Mars which will enhance the performance of the science missions as well as return higher data rate information back to Earth. With these higher data rates, the story of Martian exploration may be available in real-time around the world.

HUMAN EXPLORATION

Ultimately NASA expects that the character of the Martian exploration program will shift from a purely robotic mission deployment to the deployment of missions with human travelers. As we approach this new era, we will deploy experiments in the robotic program designed to characterize the Martian environment for human habitation and test those technologies needed to support human travel to and from Mars.

This is already the case with the Mars 2001 lander, which will carry experiments to measure the radiation environment on the Martian surface, test the soil and dust toxicity, and extract oxygen from the CO₂-dominated Martian atmosphere.

It is anticipated that the landers deployed for sample return in 2003 and beyond will also carry experiments which will pave the road for human travel to Mars. Potential experiments with the 2003 lander include the test of a mid lift/drag descent aeroshell which will slow down the lander in the Martian atmosphere with a human-tolerable g force, and an in-situ propellant production facility, which will manufacture and ignite a fuel suitable for human cargo lift-offs from the Martian surface. It is likely that experiments like these will continue to be deployed in the mission after 2003.

SUMMARY

Mars continues to be interesting, both scientifically and culturally, to people around the globe. NASA's robotic program for continuing Mars exploration will probe the planet's secrets with a reach for the existence of a biological past or presence through a campaign of bringing back to Earth carefully selected samples of Martian soil and rock. Information return from small missions augment the sample return main mission set. The program is very international in character and seeks to expand our knowledge of the planet itself and test technologies required for human travel to Mars in the next century.

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